Engineering Solid Mechanics (2017) 103-112

Contents lists available at GrowingScience

Engineering Solid Mechanics

homepage: www.GrowingScience.com/esm

Analysis of mechanical properties of jute fiber strengthened epoxy/polyester composites

Prabhakar Kaushik[a] , Jaivir[b], and Kapil Mittal[c*]

[a]*Associate Professor, Department of Mechanical Engineering,UIET, Maharshi Dayanand University, Rohtak, Rohtak, Haryana, India, 124001*
[b]*M.Tech Research Scholar, Department of Mechanical Engineering,UIET, Maharshi Dayanand University, Rohtak, Haryana, India, 124001*
[c]*Assistant Professor, Department of Mechanical Engineering, FET, Gurukul Kangri University, Haridwar, Uttarakhand, India, 249404*

A R T I C L E I N F O

Article history:
Received 6 October, 2016
Accepted 3 March 2017
Available online
3 March 2017

Keywords:
Jute fiber
Epoxy resin
Polyester resin
Experimental study
Taguchi method

A B S T R A C T

In recent years, efforts have been made to produce advanced composite materials in order to lessen environmental impact and to extent sustainability. Traditional materials are largely substituted by composites due to their greater properties like flexural strength, low thermal expansion and high strength. Numerous studies are present that show the process of composite materials reinforcement with natural fiber to improve mechanical and thermal properties. The vital aspect of exploitation of natural fiber in composites is associated with biodegradability. An extensive range of different natural fibers has been used for reinforcement till now. In present work, mechanical properties of jute fiber reinforced epoxy and polyester composites manufactured using Taguchi optimization method are investigated, experimentally. It was found that jute reinforced epoxy composite had better mechanical properties than jute polyester composite. Also, Epoxy- jute composite had lower erosion wear rate than polyester jute composites.

1. Introduction

In the history of materials, one of the most significant achievement is the evolution of composite materials and their manufacturing processes. Composite materials are used in different areas, where specific physical and mechanical properties are required. Composites have better impact strength, tensile strength, and flexural strength as compared to conventional materials (Verma, 2009). Due to these advantages, these are broadly used in the aerospace, automotive and infrastructure industries. Composite materials are produced by mixing two or more materials containing different properties and generally consist of a tougher and lighter material (Chow et al., 2007). The stronger or tougher material is known as reinforcement and lighter material is known as a matrix. Main function of matrix is to transfer stress between reinforced fibers and protect the composite from mechanical damage. Reinforcement in the composite improves the mechanical properties like flexural strength, impact

* Corresponding author.
E-mail addresses: kapilmittal007@gmail.com (K. Mittal)

doi: 10.5267/j.esm.2017.3.002

strength, tensile strength, and stiffness (Chandramohan & Marimuthu, 2011). Based on the matrix material used, composites are of three type metal matrix composites, ceramic matrix composites and polymer matrix composites (Dhanasekran & Balachandran, 2008). Each type has its definite applications. Further, in metal matrix composites, metals are used for matrix material (Girisha et al., 2014). Another term 'Ceramics' are known as inorganic and non- metallic materials that have utility in our daily lifestyle. In ceramic matrix composites, ceramic is taken as matrix material. Ceramic material contains inorganic material such as plates, pottery, bricks, glass, titles, oxides, nitrides, carbides of silicon, zirconium, aluminum, etc. (Khan et al., 2016). When polymer resins are used as matrix material with any type of reinforcement agent such as composite material, these are called as polymer matrix composites. This type of composites is mostly used because of ease of fabrication, lower cost, and good electrical & thermal insulator and lower density (Gujjala et al., 2014). The property of such composite material depends on three elements. These are: (i)Type of Polymer, (ii) Reinforcement Material and (iii) Filler Material or Interface. Polymer matrix composite are considered to be the most significant class of composite as compared with metal matrix and ceramics matrix (Onal & Adanur, 2002). These matrices are easily fabricated and have low cost. This type of matrix is classified in to two types: Thermosets polymers and Thermoplastic polymers. Thermosets polymers are most effective type of matrix system. In this, resins undergo polymerization and cross linking during curing process. These polymers do not melt on reheating, but they decompose thermally at high temperature. Examples of thermosets are unsaturated polyesters, epoxies, polyimides and vinyl esters. Composites (especially those made of natural fibers), due to their unique advantages have numerous application in todays' technically advancing environment (Pujari et al., 2014; Kumar et al. 2004; Mansourian et al., 2016; Kumar, 2016). In this paper, specimen of an Epoxy/Polyester composite consisting jute fibers has been prepared and an analysis of their mechanical properties have been made by performing certain tests.

2. Materials & experimental details

2.1 Materials

For the preparation of the specimen, jute fiber is used, as reinforcement material and epoxy\polyester are the matrix materials. Epoxy and polyester resins are supplied by 'Saakshi dye and chemicals, New Delhi'. The density of epoxy and polyester at room temperature are 1.16 and 1.09, respectively. Woven jute fibers were collected from local sources (Fig. 1).

Fig. 1. Woven Jute Fiber

2.2. Composite Fabrication

To prepare the matrix material for composite, epoxy resin, polyester resin, hardener, and accelerator are used. The epoxy resin and corresponding hardener (HY951) were mixed in a weight ratio of 10:1. Hand lay-up technique was used for the preparation of composite. A mould having dimensions 150×30×7mm was prepared. Then jute fiber in the form of woven was reinforced with epoxy and polyester separately in different weight proportions (11%, 22%, 33%, 44%, and 55%) to prepare composites. Jute fiber is laid in the mould uniformly and compressed. Then the fiber seat was removed and remover was applied to the mould. The jute fiber was kept again in mould. Resin and respective hardener were mixed separately and uniformly poured over the compressed fiber. Then the mixture was compressed again and left for a curing period of 24 hours. After completion of the curing process, samples were cut to required size as per ASTM standards. The composite samples of five different composition EJ-1 to EJ-5 which have an epoxy resin as matrix material and five other composite samples PJ-1 to PJ-5 which have polyester as matrix material were prepared. The composition of prepared samples is shown in Table 1.

Table 1. Composition of prepared samples

Sample	Composition
EJ-1	Epoxy + jute (11% by volume)
EJ-2	Epoxy + jute (22% by volume)
EJ-3	Epoxy + jute (33% by volume)
EJ-4	Epoxy + jute (44 % by volume)
EJ-5	Epoxy + jute (55% by volume)
PJ-1	Polyester + jute (11% by volume)
PJ-2	Polyester + jute (22% by volume)
PJ-3	Polyester + jute (33% by volume)
PJ-4	Polyester + jute (44 % by volume)
PJ-5	Polyester + jute (55% by volume)

2.3 Mechanical Testing

After preparation of specimen, the samples were subjected to different mechanical testing according to ASTM standards. For each composition, five specimens were tested to evaluate the mechanical properties, so that statistically significant results were obtained.

1) Flexural Test

Flexural test was performed on the specimen by using a universal testing machine. Flexural strength is the ability of a material to bend before the breaking point. The test is conducted at a constant speed of 2.38mm/min at room temperature. Dimensions of specimen for the flexural test were 150×30×7 mm^3 and standard followed was ASTM 790-03. The specimen was placed between two supports of span length 100 mm.

2) Impact Test

This test was performed on the Izod impact-testing machine. The specimen was clamped upright in an anvil. A striker carried on pendulum, which is allowed to fall freely from a fixed height, then hits the test specimen. The specimens were tested as per ASTM-D 256-05 standard. The dimension of the specimen for impact test was 64×15×7 mm^3.

*3) Erosion testing of composite specimen***:**

Erosion test rig as per ASTM G76 was used for the erosion testing of the composite specimen. The erosion test rig basically consists of an air compressor, air filter, air drying unit, hopper, mixing chamber and a vibrator which is basically connected to mixing chamber. The erodent particles basically consists of silica sand. With the help of the conveyer belt these sand particle were brought to the mixing chamber where the compress air was mixed and the mixture was allowed to pass through the converging brass nozzle of 3 mm internal diameter.

3. Taguchi experimental design

For robust design, Taguchi experimental design was used. It is a very simple and organized approach through which the design parameters can be optimized while reducing the overall testing time and experimental cost (Kaushik et al., 2016). It consists of two important tools. These tools are:

- Signal to noise ratio: - It extent quality which accentuate on variation.

- Orthogonal Array: - It holds all the design parameters at the same time.

The selection of the design parameters is a very important stage in the design of experiment. Through entire literature reconsideration of the polymer composite in case of erosion behavior, it was conformed that parameters like filler content, impact velocity, Stand off distance, Impingent angle, erodent temperature etc. affect the erosion rate of composite. For sophisticated planning of experiments Taguchi approach for four factors and three levels was used. In the Taguchi approach the array which was to be chosen was L_9 (3^4). In relation to the test it contained four columns at three levels. In the present study out of all parameters only four parameters were taken. All the four parameters were considered at each three levels. The experimental observations were converted into signal to noise ratio. Depending upon the type of characteristics, signal to noise ratios are of several types:

Smaller-the-better characteristic:

$$S/N= -10\log 1/n \{\Sigma p^2\}, \quad (1)$$

Nominal-the-better characteristic:

$$S/N= -10\log \{\Sigma P/ X^2\}, \quad (2)$$

Larger-the-better characteristic:

$$S/N= -10\log 1/n \{\Sigma 1/p^2\}, \quad (3)$$

where n is the number of observation, p is data observed, P is the mean and X is the variance. Under the smaller the better, the S/N ratio was minimum for erosion rate, which can be calculated from Eq. (1). Whole scheme is elaborated in Tables (2-4).

Table 2. Parameters set for erosion test

Control factor	Symbols	Fixed parameters	
Impact Velocity	Factor A	Erodent	Silica sand
Impingent Angle	Factor B	Nozzle Diameter	3 mm
Erodent Size	Factor C	Stand Off Distance	100 mm
Fiber Loading	Factor D	Length Of Nozzle	80 mm

Table 3. Control factors for each level

Control factor	Level			Units
	1	2	3	
Impact Velocity	35	45	55	m/sec
Impingent Angle	30	60	90	Degree
Erodent Size	300	400	500	µm
Fiber Loading	22	33	44	% by volume

Table 4. Orthogonal arrays for L_9 Taguchi design

SR. No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	2	3
9	3	3	1	1

4. Results and discussion

The specimens were tested for their flexural and impact strength and following results were obtained.

4.1 Flexural Test

Table 5 gives the values of flexural strength of a specimen with different fiber loading for jute-reinforced epoxy/polyester composites.

Table 5. Flexural strength of composite specimen

Sample	Value in n/mm²
EJ-1	25.31
EJ-2	32.47
EJ-3	36.45
EJ-4	47.67
EJ-5	33.84
PJ-1	12.77
PJ-2	14.71
PJ-3	17.03
PJ-4	20.23
PJ-5	19.91

Fig. 2 shows the flexural strength of jute polyester composite. Flexural strength increases up to 44 % of fiber loading and then start decreasing with further increase in fiber loading. It was also observed that at 11% composite shows lower impact strength. The maximum flexural strength obtained is 20.23 N/mm^2 and minimum value obtained for flexural strength is 12.77 N/mm^2 with 11% fiber loading.

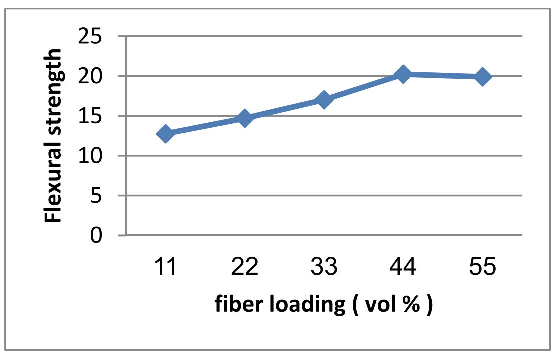

Fig. 2. Flexural Strength of Jute Polyester Composite

The flexural strength of jute-reinforced epoxy composites is shown in Fig. 3. For jute-epoxy composite the maximum value of flexural strength came out to be 47.67 N/mm^2 obtained at 44% fiber volume fraction and minimum value was 25.31 N/mm^2 obtained at 11%. The impact strength increases up to 44% of fiber loading and after that starts decreasing as the fiber content increases.

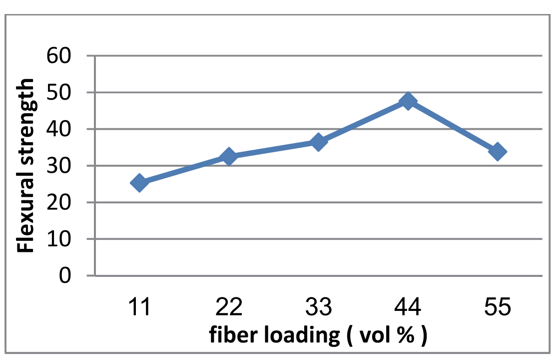

Fig. 3. Flexural Strength of Jute-Epoxy Composite

Fig. 4 shows the comparison of flexural strength between jute reinforced epoxy and polyester composites. Jute reinforced epoxy composite have more flexural strength as compared to jute-polyester composite. For jute-epoxy composite, the flexural strength was 35.14 N/mm^2 and for jute-polyester composite was 16.93 N/mm^2.

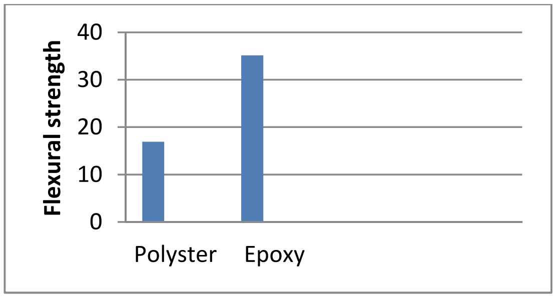

Fig. 4. Comparison between Flexural Strength of Jute Reinforced Epoxy/Polyester Composite

4.2 Impact Test

Table 6 shows the values of impact strength for different specimens. Fig. 5 shows the results of impact strength of jute reinforced polyester composites. From the values obtained, it was observed that at 44% of fiber loading maximum value of impact strength was achieved. Moreover, with an increase in the fiber loading impact strength increases up to 44% fiber content. A further increase in the fiber loading relatively decreased the impact strength. The minimum value of impact strength was 81.74 J/m^2 observed at 11% fiber loading and maximum strength was 148.58 J/m^2 at 44 % fiber loading.

Table 6. Impact strength of different specimens

Sample	Value in j/m
EJ-1	20.39
EJ-2	46.55
EJ-3	73.33
EJ-4	110.74
EJ-5	99.42
PJ-1	81.74
PJ-2	108.54
PJ-3	132.83
PJ-4	148.58
PJ-5	119.7

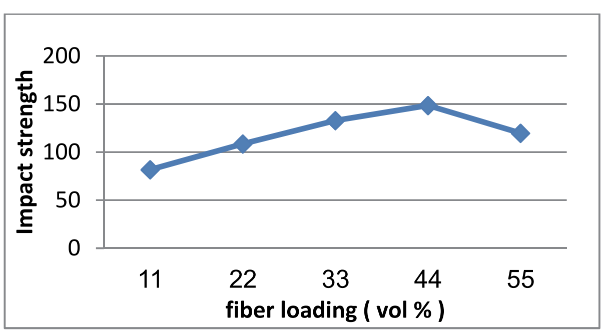

Fig. 5. Impact Strength of Jute-Polyester Composite

Similarly, in case of jute-epoxy composite, impact strength changes with the fiber volume fraction as shown in Fig. 6. Impact strength of epoxy composite was minimum at 11% fiber loading and maximum at 44%. A further increase in fiber loading subsequently decreased the impact strength.

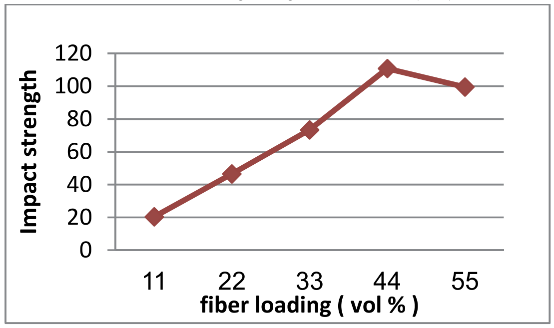

Fig. 6. Impact Strength of Jute-epoxy Composite

A comparison between the impact strength of jute reinforced epoxy-polyester composites is shown in Fig. 7 in form of a graph. It explains that polyester based composites have better impact strength as compared to epoxy-based composites. Impact strength of polyester based composite was 118.28 J/m^2 and for epoxy based composite was 70.04 J/m^2. It was also observed that for both epoxy and polyester based composites 44% fiber volume fraction was best to obtain maximum impact strength.

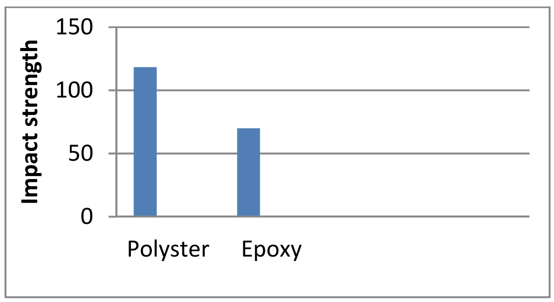

Fig. 7. Comparison between Impacts Strength of Jute Reinforced Epoxy/Polyester Composite

4.3 Erosion Test

Part 1: Jute-Polyester Composites

The analysis of Taguchi experiment was performed using MINITAB 17 software. Using Taguchi approach and orthogonal array L_9 an experiment was designed for all possible combination of control factors and corresponding levels before measuring the performance of composites. The calculated erosion rate of jute fiber reinforced polyester composite for 9 different combination over 4 important factors (discussed earlier in Table 2) is as follows (Table 7):

Table 7. S/N Ratio and Erosion Rate for Jute-Polyester Composite

SR. No	A	B	C	D	ER	S/N RATIO
1	35	30	300	22	196.987	-45.8888
2	35	60	400	33	237.689	-47.5202
3	35	90	500	44	251.231	-48.0015
4	45	30	400	44	264.852	-48.4601
5	45	60	500	22	238.124	-47.5543
6	45	90	300	33	226.481	-47.1006
7	55	30	500	33	267.157	-48.5353
8	55	60	300	44	298.364	-49.4947
9	55	90	400	22	257.743	-48.0536

It is evident from the table that the most significant factor is the impingement angle which is followed by impact velocity and then fiber loading while the factor erodent size is the least significant factor in erosion of jute reinforced polyester composite. For the erosion rate the mean of the S/N ratio is -47.8454 db. The effect of each factor is shown in Fig. 8 and Table 8.

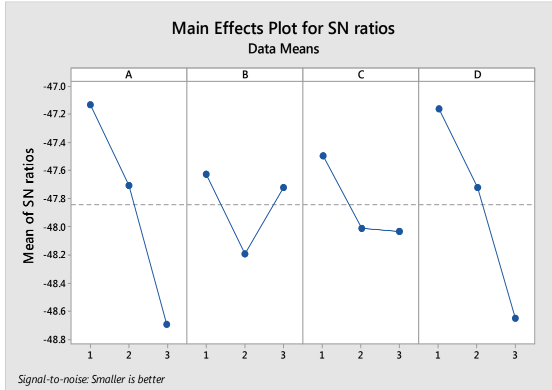

Fig. 8. Effect of Control Factors

Table 8. Response Table for S/N Ratios (smaller is better)

Level	A	B	C	D
1	-47.14	-47.63	-47.49	-47.17
2	-47.70	-48.19	-48.01	-47.72
3	-48.69	-47.72	-48.03	-48.65
Delta	1.56	0.56	0.54	1.49
Rank	1	3	4	2

Part 2: Jute Epoxy Composite

The calculated erosion rate of jute epoxy composite for 9 different combinations over 4 important factors (discussed earlier in Table 2) is as follows (Table 10):

Table 9. S/N ratio and erosion rate for different test conditions

SR. No	A	B	C	D	ER	SN RATIO
1	35	30	300	22	151.810	-43.6260
2	35	60	400	33	166.465	-44.4265
3	35	90	500	44	182.345	-45.2179
4	45	30	400	44	196.765	-45.8790
5	45	60	500	22	172.879	-44.7545
6	45	90	300	33	191.463	-45.6417
7	55	30	500	33	204.879	-46.2299
8	55	60	300	44	227.980	-47.1579
9	55	90	400	22	198.678	-45.9630

From Table 9 it is clear that the most significant factor among all the factors is the impact velocity which is followed by fiber content and then impingement angle while the factor erodent size is the least significant factor in erosion of jute reinforced epoxy composite. For the erosion rate the mean of the S/N ratio is -47.8454 db. The effect of each factor is as shown in Fig. 9 and Table 10.

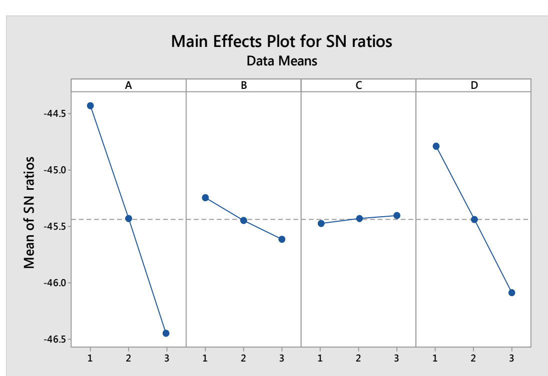

Fig. 9. Effects of Control Factors

Table 10. Response table for S/N ratios (smaller is better)

Level	A	B	C	D
1	-44.42	-45.24	-45.48	-44.78
2	-45.43	-45.45	-45.42	-45.43
3	-46.45	-45.61	-45.40	-46.08
Delta	2.03	0.36	0.07	1.30
Rank	1	3	4	2

5. Conclusions

In current work, experiments were carried out to find the flexural and impact strength of jute reinforced epoxy and polyester composites for different fiber loadings. The following conclusions could be obtained from the experimental results.

1. The flexural and impact properties of jute fiber reinforced epoxy and polyester composite have been considerably enhanced with the various fiber volume fractions.
2. It was found that with the increase in the fiber volume fraction, flexural strength also increases. Maximum flexural strength was achieved at 44 % volume fraction of fiber for both jute reinforced epoxy and polyester composites.
3. Impact strength increased with an increase in the fiber volume fraction and was maximum at 44 %. Overall, it was obtained that at 44% volume fraction of the jute fiber composite showed the maximum mechanical properties.
4. Maximum flexural strength obtained for jute-reinforced epoxy composite was 47.67 N/mm^2, while for jute reinforced polyester composite it was 20.23 N/mm^2. Thus jute reinforced epoxy composite have better flexural strength as compared to jute reinforced polyester composites.
5. Maximum impact strength obtained for jute-reinforced epoxy composite was 110.74 J/m^2. While for jute-reinforced polyester composite it is 148.58 J/m^2. So jute-reinforced polyester has better impact strength.
6. The results obtained by this research indicate that jute reinforced epoxy composite have better mechanical properties than jute polyester composite.
7. Erosion behaviors of composite have been successfully analyzed by Taguchi experimental design. Significant control factors affecting the erosion rate have been identified through this technique.
8. Results showed that impact velocity is highly influencing control factor for erosion rate. After that fiber loading and impingent angle are most contributing factors. Least influencing control factor for erosion rate is erodent size.
9. Epoxy- jute composite have lower erosion wear rate than polyester jute composites.

References

Chandramohan, D., & Marimuthu, D. K. (2011). Tensile and hardness tests on natural fiber reinforced polymer composite material. *International Journal of Advanced Engineering Science and Technology*, *6*(1), 97-104.

Chow, C. P. L., Xing, X. S., & Li, R. K. Y. (2007). Moisture absorption studies of sisal fibre reinforced polypropylene composites. *Composites Science and Technology*, *67*(2), 306-313.

Dhanasekaran, S., & Balachandran, G. (2008). *Structural behavior of jute fiber composites-A review* (No. 2008-01-2653). SAE Technical Paper.

Girisha, K. G., Anil, K. C. & Akash, A. (2014). Mechanical properties of jute and hemp reinforced epoxy/polyester hybrid composites. *International Journal of Research in Engineering & Technology*, ISSN, 2321-8843.

Gujjala, R., Ojha, S., Acharya, S. K., & Pal, S. K. (2014). Mechanical properties of woven jute–glass hybrid-reinforced epoxy composite. *Journal of Composite Materials*, *48*(28), 3445-3455.

Kaushik, P., Mittal, K., & Rana, P. (2016). Energy paybacks of six-sigma: A case study of manufacturing industry in India. *Management Science Letters*, *6*(11), 691-700.

Khan, G. A., Terano, M., Gafur, M. A., & Alam, M. S. (2016). Studies on the mechanical properties of woven jute fabric reinforced poly (l-lactic acid) composites. *Journal of King Saud University-Engineering Sciences*, *28*(1), 69-74.

Kumar, R. (2016). A review on epoxy and polyester based polymer concrete and exploration of Polyfurfuryl Alcohol as polymer concrete. *Journal of Polymers*, *2016*.

Kumar, P., Sikdar, P. K., Bose, S., & Chandra, S. (2004). Use of jute fibre in stone matrix asphalt. *Road Materials and Pavement Design*, *5*(2), 239-249.

Mansourian, A., Razmi, A., & Razavi, M. (2016). Evaluation of fracture resistance of warm mix asphalt containing jute fibers. *Construction and Building Materials*, *117*, 37-46.

Onal, L., & Adanur, S. (2002). Effect of stacking sequence on the mechanical properties of glass–carbon hybrid composites before and after impact. *Journal of Industrial Textiles*, *31*(4), 255-271.

Pujari, S., Ramakrishna, A., & Suresh Kumar, M. (2014). Comparison of Jute and Banana Fiber Composites: A Review. *International Journal of Current Engineering and Technology*.

Verma, B. B. (2009). Continuous jute fibre reinforced laminated paper composite and reinforcement-fibre free paper laminate. *Bulletin of Materials Science*, *32*(6), 589-595.